DEVELOPMENT OF AN ARCGIS- POLLUTANT LOAD APPLICATION (PLOAD) TOOL

A Thesis

by

DE'ETRA JENRA YOUNG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2006

Major Subject: Forestry

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ABSTRACT

Development of an ArcGIS-Pollutant Load Application (PLOAD) Tool. (August 2006)

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Chair of Advisory Committee: Dr. Raghavan Srinivasan

Many of the findings of previous studies have indicated that there is a direct correlation between water quality and urbanization. Increasing impervious coverage typically results in a decrease in water quality. The purpose of this study was to adapt an automated tool for assessing the Pollutant Load Application (PLOAD). Created by CH2M HILL, a full-service engineering and construction enterprise, PLOAD is a simplified GIS-based model used to calculate pollutants within a watershed. The so-called "simple method" implemented by PLOAD and discussed in this thesis has been endorsed by the EPA as a viable screening tool for National Pollutant Discharge Elimination System (NPDES) stormwater projects. This model was designed to be used with ArcView 3.3. ArcView 3.3 is a depreciated product, the capabilities of which have been replaced by ArcGIS 9.1. Using the same GIS data and tabular data required by PLOAD and custom ArcObjects scripting, a replacement, ArcGIS-PLOAD, was created. The current version of ArcGIS-PLOAD implements the "simple method" to calculate total pollutant load in pounds per year based on basin boundaries, precipitation in inches per year, ratio of storms producing runoff, parcel land use and parcel area, runoff coefficient for each land use, event mean pollutant concentrations for each land use. Time comparisons between the original PLOAD and the new ArcGIS-PLOAD revealed significant improvements. Both

versions of PLOAD produce an intersection between the basin boundary and the land use layer. Calculations are actually done to the intersect layer. It was also found that the original PLOAD disregarded an albeit small portion of the intersection polygons. The new version does not. With the creation of ArcGIS-PLOAD, it is anticipated that it will become a small step in assist the State of Texas in improving water quality.

ACKNOWLEDGEMENTS

Without the guidance, support and love of several people this thesis would not have been attainable. First, I want to thank God, for giving me the strength and wisdom to complete this thesis. Secondly, I would like to express my appreciation to Dr. Raghavan Srinivasan for his “open door” policy which allowed invaluable help for this project and for allowing me the opportunity to work in the Spatial Sciences Lab. In addition, I would like to thank my committee members, Dr. Samuel Brody, Dr. Marian Eriksson, and Dr. Todd Watson for being very influential in helping me complete this thesis. Dr. Eriksson, thanks for keeping your office open and reassurance that this study was attainable.

I would like to thank all of my family and friends, including my loving parents, my sister, and Aunt Joyce, for their never-ending encouragement, love and support. Without you all, I do not think that this degree would have been possible.

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CHAPTER I

INTRODUCTION

Over the past 50 years, population growth in the United States has resulted in rapid urban development (U.S. EPA 2006a). Much attention has been given to ameliorate this problem. Population growth creates a high demand for water and leads to the urbanization of the nation's watersheds (U.S. EPA 2006a).

According to the U.S. Soil Conservation Service (1986), if a watershed is covered or will be covered by a significant area of impervious structures it is considered to be urban or urbanizing. When impervious surface increases, it transforms the characteristics of watersheds and decreases water quality (U.S. Soil Conservation Service 1986). There have been many relationships between water quality and the amount of impervious surface cover established in previous studies (Gnecco *et al.* 2005, Arnold and Gibson 1996, Stoel 1999). Ritchie *et al*. (2002) studied the problems associated with global change and suitable development. In this special issue written for *Hydrological Processes*, the study applied Geographic Information Systems (GIS) and Remote Sensing to find similar patterns between erosion and water quality. Asano (2005) focused attention on the effects of increasing urbanization and pressures on water supplies and water pollution.

This thesis follows the style of *International Journal of Geographical Information Science.*

There is an established association that commonly exists between pollution loading associated with impervious structures and land use/land cover (LULC) change (U.S. EPA 2006a). Because a relationship exists among pollution loading and land use, there is potential to advance our nations water quality with land use management practices aimed at reducing pollution (Basnyat *et al.* 2000). When there is a change in water quality, there is a probable indicator in some aspect of terrestrial, riparian, or in-channel ecosystem that can be observed (Basnyat *et al.* 2000).

An impervious structure is defined as a feature that disallows water from penetrating the ground naturally. Concrete, pavement, and other impermeable surfaces, such as rooftops and swimming pools, are all features of urban landscapes and are considered as impervious surfaces. One can also identify and assess impervious land cover because it is considered land that is not “green” (Schueler 1994) and not soil. Unlike pervious land structures, which act as sponges to for nonpoint source (NPS) pollutants, pollutants deposited on impervious structures pollutants are displaced through storm water runoff. These pollutants include excess nutrients and sediments, oil, gasoline, and other toxins (Arnold and Gibbons 1996). This occurrence has been identified and recognized as the leading threat to water quality in the United States (U.S. EPA 1994).

According to the Environmental Protection Agency (EPA), it is estimated that it will have to substantially increase its spending budget by $263 billion over the next 20 years to sufficiently improve and maintain its water services (U.S. EPA 2006b). As such, an increased demand for particular GIS-aided pollution simulation tools is anticipated. Such tools will aid decision makers in examining the broad effects of shifting lands to different users and implementing ameliorating “best” management practices.

1.1 Objectives

In an attempt to quantify the pollution in our nation’s watersheds, CH2M HILL water resource engineers and GIS analysts developed the Pollutant Load Application (PLOAD) computer program (U.S. EPA 2001a). Using either the “pollutant export coefficient” or “simple method” annual pollutant loads are calculated for watersheds. In addition, the pollutant loads that are derivatives from these equations may be refined based on the remedial effects of Best Management Practices (BMPs) (U.S. EPA 2001a). Simulation runs based on a variety of BMP-specifications allow for comparative studies that can be used in decision-making in order to “optimize” management practices thus “minimizing” watershed pollutant load.

PLOAD was written in the Avenue scripting language to run under ESRI’s ArcView 3.3. With ArcView 3.3 being a deprecated product, the capabilities of which has been replaced by ArcGIS 9.1, the purpose of this research was to port one of the PLOADs’s two estimation methods to ArcGIS 9.1. The specific objective of this study was to efficiently implement PLOAD’s “simple method.” Mimicking as closely as possible the original PLOAD dialogs (forms). “Efficiently” here is defined as computer-efficiently;

that is, use time-efficient code. The revised product will be here in be referred to as ArcGIS-PLOAD. The second estimation method and the incorporation of the best management option and moving ArcGIS-PLOAD to web based application are left for future development.

CHAPTER II

RELEVANT LITERATURE

Environmental impacts, such as on water quality, can be difficult to see visually or spatially. They are also costly to measure and are rarely known with certainty. As a result, models need to be constructed to evaluate probable environmental impacts of alternative development strategies. The use of models allows researchers to identify sources of existing or potential problems and helps decision makers facilitate change. These models require a diversity of assumptions and often call for visual support, such as that provided by geographic information system (GIS), to facilitate significant communication of the results. GIS is a useful tool for studying pollution and water quality in particular, since they are often related, at least in part, to land use which has a spatial extent.

2.1 Geographic Information Systems

A GIS is as a computer package that stores and manipulates spatial data and, importantly, powerful capabilities for data analysis and modeling (Heywood *et al*. 2002). Tim and Jolly (1999) defined GIS as having the ability to "efficiently store, manipulate, retrieve, analyze and display geo-referenced spatial and nonspatial data." The product used in this research run on a standard desktop computer to "create, import, edit, query, map, analyze, and publish geographic information," (ESRI 2006). GIS operates on the fundamental types of spatial data: points, lines and polygons. They may be strictly raster (grid)-based, vector (directed line segments)-based, or they may have combined capabilities. A polygon can be defined as a many-sided vector graphic used to represent an area and is formed from a closed chain of points beginning and ending at the same point (Heywood *et al.* 2002). A layer, which is conceptually similar to themes (ArcView 3.3), is a reference to a data source; it defines how the data should appear visually on the map (ESRI 2006). Layer can be feature layers comprised of the fundamental shapes above, raster layers (grids, such as obtained from satellite imagery), or a few other specialized layer-types such as TINS (which includes elevation data). An intersection is a geometric combination of spatial datasets which preserve the features that fall within areas common between the two layers (ESRI 2006).

In the 1960s there were extensive attempts to use computers to process geographic data, embarking on the beginning of GIS (Goodchild 2003). Providing tools to aid in the management of our environment and natural resources has been a primary force in the development in GIS (Goodchild 2003). In the mid 1960s, the first GIS was created in Canada by the Canada Land Inventory (Goodchild 2003). The Canada Geographic Information System was used to handle the abundance of mapped information and to provide this data to the Government of Canada. In 1969, Jack and Laura Dangermond founded Environmental Systems Research Institute (ESRI). In 1973 ESRI was incorporated and selected to provide the first commercially developed statewide GIS, called the Maryland Automated Geographic Information Systems, for the State of Maryland (ESRI 2006).

Today, GIS is a vital component in environmental research, teaching, and planning (Goodchild 2003). Recently, Forkenbork and Schweitzer (1999) have developed a GIS-based application that integrates models of air pollution, vehicle emissions, pollution dispersion and noise to estimate disparate impacts of transportation development especially those affected by class and race. GIS has been pioneered as one of the primary tools for environmental planning and natural resources activities (Tim and Jolly 1994). Kelsey *et al.* (2004) identified specific land-use characteristics that contributed to nonpoint source fecal coliform bacterial pollution to enable targeted water quality management strategies using GIS. In addition, GIS was used as a successful foundation for an efficient geomorphic model to predict runoff and sediment yield over large spatial scales (Mashriqui *et al.* 1997). Lee *et al.* (2003) developed a statistical model for groundwater quality assessment in urban areas using GIS. Concentrations of nitrogen, well depth and distribution of rainfall were analyzed in South Korea.

2.1.1 *Environmental Systems Research Institute Inc.'s Systems*

Founded as a private consulting firm that specialized in land use analysis projects, ESRI's early mission focused on organizing and analyzing geographic data (ESRI 2006). In 1982, ESRI initiated its first commercial GIS software called ARC/INFO. The 1990s ESRI released ArcView. ArcView was developed as "an affordable, easy-to-learn desktop mapping tool," (ESRI 2006). In April of 2001, ESRI created ArcGIS 8.1, "a scalable system for geographic data creation, management, integration, analysis, and dissemination for every organization, from an individual to a globally distributed network of people," (ESRI 2006). Created in May 2004, ArcGIS Desktop became available form ESRI. ArcGIS is an incorporation of GIS software to build a complete GIS package (ESRI 2006). The most vital application in the ArcGIS Desktop is ArcMap. ArcMap is used for all map-based such as cartography, map analysis, and editing. ArcGIS Desktop is *extensible* in the sense that it implements Microsoft's Visual Basic for Application (VBA) (ESRI 2006). This allows ArcGIS Desktop user-developers to create custom programs that run on top of ArcGIS Desktop and extend and/or automate the GIS functionality.

2.1.2 *Environmental Systems Research Institute Inc.'s (ESRI) ArcObjects*

A simplified version of Visual Basic, VBA is object-oriented programming language. Included in the ArcGIS desktop, VBA was designed to be embedded within applications. It has it own set of development tools. The code is organized in procedures, which are the instructions needed to accomplish the defined tasks.

Created as the development platform for the ArcGIS family of applications, ArcObjects was developed as a set of "computer objects that was specifically designed for programming with ArcGIS desktop applications," (Burke 2003). ArcObjects has the ability to include objects such as data frames, layers, features and is the "framework that lets you create domain-specific components from other components," (ESRI 2006). The most common way to customize ArcGIS Desktop is through VBA. This is a major advantage since the extension allows macros to be embedded within the ArcGIS Desktop. Customizing through VBA will allow developers to achieve customization needs.

Thorp *et al.* (2005) created a tool within the VBA environment of ArcGIS using ArcObjects to create a crop model simulation for studying precision management of crop production inputs. Palladini (2004) constructed an Automated Zoning Procedure using ArcObjects to take advantage of the GIS environment to implement the concept of zoning improving as a pseudo-solution to the Modifiable Areal Unit Problem (MAUP).

2.2 Pollutant Load Application (PLOAD)

A versatile environmental analysis system for use by regional, state and local agencies in performing watershed and water quality studies, Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) was developed by the U.S. Environmental Protection Agency's Office of Water. BASINS seeks to "facilitate examination of environmental information, support analysis of environmental systems and provide a framework for examining management alternatives," (U.S. EPA 2001b). PLOAD will be used in this study.

Created by CH2M HILL and endorsed by the EPA (U.S. EPA 2001a) , PLOAD is a simple GIS-based model that can be utilized to calculate pollutant loads for specific watersheds (U.S. EPA 2001a). PLOAD has the capability of estimating nonpoint source (NPS) pollution for urban, suburban and rural watersheds on an annual basis. It has the ability to estimate total suspended solids, nutrients, metals, and fecal coliform. It requires the following inputs:

- GIS land use polygon layer,
- GIS watershed polygon layer,
- Event Mean Concentration Data,
- Optimally it allows specifications of best management practices (BMPs).

This modeling tool was created to be very general, therefore allowing it to be applied as a “screening tool” for broad applications, which include watershed management and reservoir protection projects. One has the choice of one of the two estimation methods the “simple” method and the “export coefficient” method. The “simple” method is suggested to be used for urban areas while the “export coefficient” method is for more rural areas (U.S. EPA 2001a). PLOAD produces both graphical and tabular outputs. A graphical output includes maps with watersheds for the study area, symbolized in graduated color per watershed boundary, depicting total pollutant lb/yr. Tabular output include summery tables for total pollutants in lb/yr or in lb/ac/yr by watershed and a table of total pollutants by watershed by land use in lb/yr and lb/ac/yr. Ancillary summarize such as flow (ac.ft/yr) can also be viewed.

2.3 Nonpoint Education of Municipal Officials (NEMO)

NEMO was conceived as a project to use advanced technologies as tools to educate local municipal officials and decision makers about the links between land use and water quality (NEMO 2003). In particular “to teach local land use officials about the link between land use and water quality thereby encouraging the consideration of construction, site plan and zoning alternatives that would minimize future increases in impervious structures,” (Arnold *et al.* 2000) According to NEMO (2003), “its project track record shows that effective, carefully planned educational programs conducted by professionals can catalyze and facilitate change”. NEMO’s main goal is to protect natural resources. NEMO has been able to accomplish its goal by providing education to targeted audiences, which generally include local officials. In a 3-year project funded by the U.S. Department of Agriculture, NEMO contributed to reducing water pollution by making an educational slide presentation focusing on water quality and watersheds available to participants (NEMO 2003). An interactive GIS-Base impervious surface model that estimates imperviousness was developed by the Northeast Regional Earth Science Application Center to be used as an educational tool for NEMO (Prisloe *et al.* 2001). NEMO provides a number of fact sheets on NPS water pollution, open space development, habitat fragmentation and many other topics. NEMO strives to inform local officials about the relationships between urbanization and decreased water quality, using geographic information systems as an interactive tool to educate interested parties about the environmental impacts of urbanization.

CHAPTER III

MATERIALS AND METHODS

PLOAD requires, and optionally allows for, a variety of inputs. Collection of viable data is necessary to ensure that there is an accurate depiction of the effects of urban sprawl on water quality. Data used to develop the port of PLOAD to ArcGIS-PLOAD were provided by the Texas Coastal Watershed Program (TCWP). In 2002, TCWP, a joint effort between the Texas Sea Grant and Texas Cooperative Extension was established and became the first Texas program to join the NEMO network (TCWP 2005). TCWP's ultimate goal is to provide land use planners, policy makers and citizens the education and outreach that makes the connection between land use and water quality. TCWP established a clearinghouse of data to make it readily available to the public. This comprehensive collection of GIS data layers can be used in developing user-friendly GIS interfaces. The collection of Harris County watershed and The Houston Galveston Area Council land use data were pertinent for this study and will be used.

3.1 Input Data

3.1.1 *Land Use Land Cover Data*

The Houston-Galveston Area Council(H-GAC) Land Cover data was used for this study. Land cover data has a strong influence on the dynamics of water quality through individual watersheds. It is one indicator of the relationship between environmental and human influences affecting waterways and water quality.

This data set was based on the 2001 and 2002 Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced TM satellite imagery. Four scenes were used to cover the entire region. The Land Cover Classification system (table 3.1) is based on the National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean's Program's Coastal Change Analysis Program (C-CAP). This system reflects the ecological relationships, and focuses on classes that can be discriminated from primarily satellite remote sensed data (figure 3.1).

An accuracy assessment of this data was conducted by the H-GAC (H-GAC 2006). This assessment consisted of a stratified random sampling scheme with a target of 75-100 sample points per land cover class. The results of the conservative accuracy assessment include an overall Kappa coefficient of 71% and an overall accuracy of 75% for the raw pixel classification. The results of the optimistic accuracy assessment produced an overall accuracy of 94% and a Kappa coefficient of 92%.

Table 3.1. Table from the Houston-Galveston Area Council (H-GAC) for land use land cover (LULC) for Harris County. The LULC is based on the Anderson's Classification and is the generalized first and second level steps of the classification of land use (TCWP 2005).

LULC_CODE	**DESCRIPTION**	**AREA (sq.mi.)**
11	LD LOW-INTESITY DEVELOPED	653.17
16	HD HIGH-INTENSITY DEVELOPED	12.24
21	AG CULTIVATED LAND (AGRICULTURE)	540.95
31	GR GRASSLAND	375.28
43	WO WOODY LAND (WOODLAND)	76.48
52	WA OPEN WATER	54.81
61	WW WOODED WETLAND (FORESTED WETLAND)	30.41
62	WE WETLAND	33.65
76	BA BARE LAND OR TRANSITIONAL	15.02
	TOTAL	1776.66

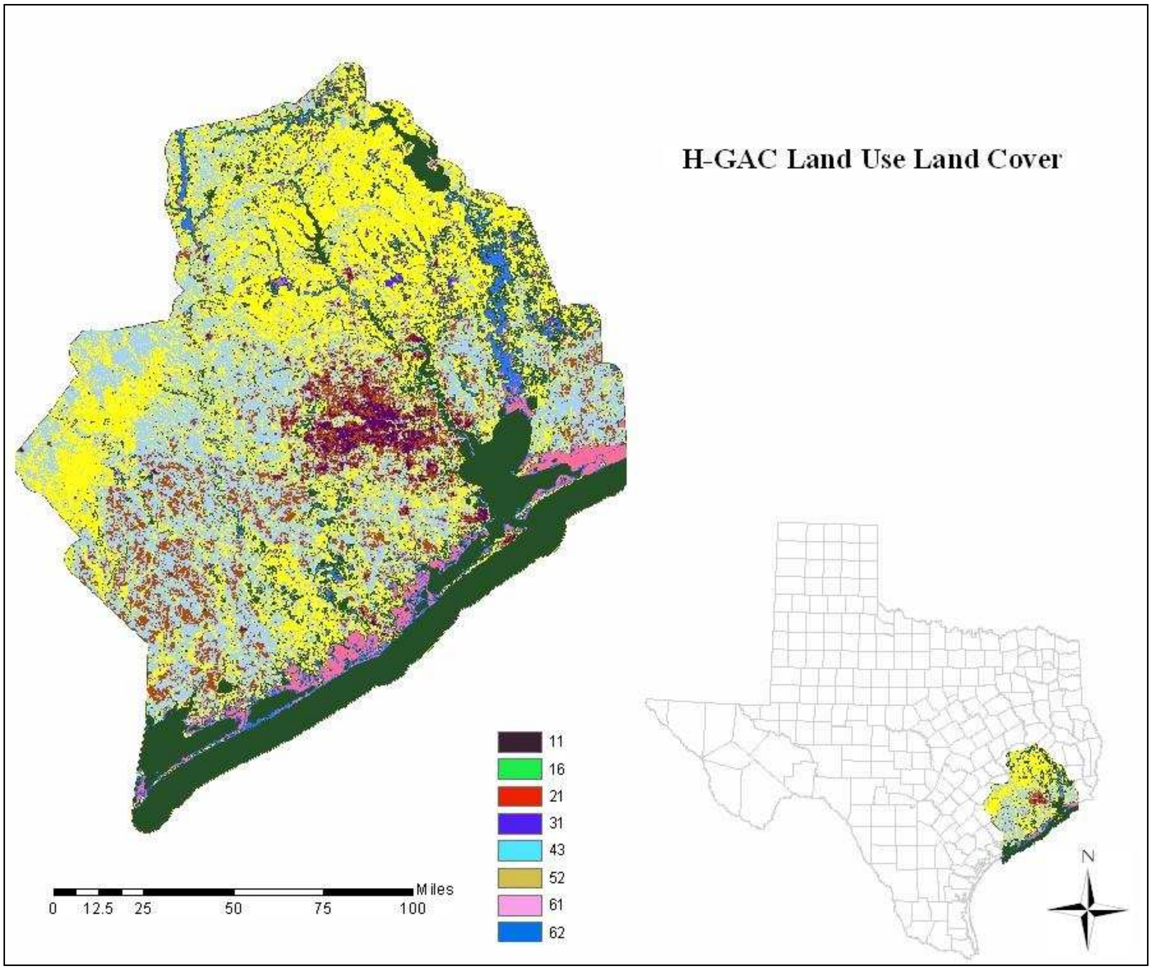

Figure 3.1. Houston-Galveston Area Council land use cover data (TCWP 2005).

3.1.2 *Watershed Data*

To define the areas for which the pollutant loads are calculated, the watershed data is needed for PLOAD. This data was obtained from the National Hydrography Dataset (NHD).

3.1.3 *Intersection Layer*

ArcPLOAD and ArcGIS-PLOAD completes the calculations on the intersection layer. There are a total of 364,795 polygons in the intersection layer.

3.2 Tabular Data

Pollutant loading rate and impervious percent are required as input to ArcGIS-PLOAD. These data were accumulated in Microsoft Excel worksheets that are read by the current version of ArcGIS-PLOAD.

3.2.1 *Event Mean Concentration (EMC)*

The pollutant loading tables consist of the EMC and the export coefficient to be used in by ArcGIS-PLOAD. These tables contain the pollutant rates for urban and rural land use types.

The EMC table (table 3.2) was derived from an extensive literature review prepared by TCWP. The values depend on the nutrients under consideration and land-use. For the purposes of this project, it was decided that the Texas EMC values were the most appropriate to use. The data include nonbacterial pollutants and have units of mg/l. The fields include: TN-Total Nitrogen, BOD-Biochemical Oxygen Demand, TSS-Total Suspended Solids, and TP-Total Phosphorus.

Table 3.2. Event Mean Concentration table measured in milligrams per liter for total nitrogen (TN), biochemical oxygen demand (BOD), total suspended solids (TSS), and total phosphorus (TP). The LULC is based on the Anderson's Classification and is the generalized first and second level steps of the classification of land use (TCWP 2005).

LULC_CODE	Classification	TSS	BOD	TN	TP
11	RESIDENTIAL	100	15	3.41	0.79
12	COMMERCIAL AND SERVICES	166	9	2.1	0.37
13	INDUSTRIAL	166	9	2.1	0.37
14	TRANS, COMM, UTIL	166	9	2.1	0.37
15	INDUST & COMMERC CMPLXS	166	9	2.1	0.37
16	MXD URBAN OR BUILT-UP	166	9	2.1	0.37
17	OTHER URBAN OR BUILT-UP	166	9	2.1	0.37
21	CROPLAND AND PASTURE	201	4	1.56	0.36
22	ORCH, GROV, VNYRD, NURS, ORN	201	4	1.56	0.36
23	CONFINED FEEDING OPS	201	4	1.56	0.36
24	OTHER AGRICULTURAL LAND	201	4	1.56	0.36
31	HERBACEOUS RANGELAND	70	6	1.51	0.12
32	SHRUB & BRUSH RANGELAND	70	6	1.51	0.12
33	MIXED RANGELAND	70	6	1.51	0.12
41	DECIDUOUS FOREST LAND	39	6	0.83	0.06
42	EVERGREEN FOREST LAND	39	6	0.83	0.06
43	MIXED FOREST LAND	39	6	0.83	0.06
51	STREAMS AND CANALS	3	22	26	0
52	LAKES	3	22	26	0
53	RESERVOIRS	3	22	26	0
61	FORESTED WETLAND	39	6	0.83	0.06
62	NONFORESTED WETLAND	39	6	0.83	0
74	BARE ROCK EXPOSED	2200	13	5.2	0.59
75	STRIP MINES	2200	13	5.2	0.59
76	TRANSITIONAL AREAS	2200	13	5.2	0.59

3.2.2 *Impervious Factor Table*

The impervious factor data table (table 3.3) contains the percent imperviousness that is associated with each land use. This table is used to calculate the EMC runoff coefficient. This table identifies the Land use code and the imperious percentage. This data was obtained from TCWP. The data is in the format of impervious fraction.

Table3.3. Impervious factor data identifying the percentage of imperviousness. Percent imperviousness if for each of Anderson's land use land cover classification (TCWP 2005).

LULC_CODE	**Classification**	**IMPERVIOUS PERCENTAGE**
11	RESIDENTIAL	0.5
12	COMMERCIAL AND SERVICES	0.85
13	INDUSTRIAL	0.72
14	TRANS, COMM, UTIL	0.65
15	INDUST & COMMERC CMPLXS	0.75
16	MXD URBAN OR BUILT-UP	0.6
17	OTHER URBAN OR BUILT-UP	0.15
21	CROPLAND AND PASTURE	0.02
22	ORCH, GROV, VNYRD, NURS, ORN	0.02
23	CONFINED FEEDING OPS	0.25
24	OTHER AGRICULTURAL LAND	0.02
31	HERBACEOUS RANGELAND	0.02
32	SHRUB & BRUSH RANGELAND	0.02
33	MIXED RANGELAND	0.02
41	DECIDUOUS FOREST LAND	0.02
42	EVERGREEN FOREST LAND	0.02
43	MIXED FOREST LAND	0.02
51	STREAMS AND CANALS	1
52	LAKES	1
53	RESERVOIRS	1
61	FORESTED WETLAND	0.02
62	NONFORESTED WETLAND	0.02
74	BARE ROCK EXPOSED	1
75	STRIP MINES	0.5
76	TRANSITIONAL AREAS	0.5

3.2.3 *Best Management Practices (BMP) Efficiency Table*

Containing the percentage removal efficiency multipliers for each BMP type, the BMP table (table 3.4) was provided by the TCWP. This table was developed by water resource engineers by use of literature values. The table identifies the BMP type and the pollutants under evaluation.

Table 3.4. Best Management Practices (BMPs) and pollutants.
Pollutants are in percent of reduction for total suspended solids (TSS), biochemical oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP) (TCWP2005).

BMP TYPE	**BMP**	**TSS**	**BOD**	**TN**	**TP**
WP	WET POND	92	30	19	80
DB	DRY DETENTION POND	45	20	30	30
DP	DETENTION POND	75	30	40	60
CW	CONSTRUCTED WETLAND	65	30	20	30
GS	GRASSED SWALES	45	20	30	30
VS	VEGETATED FILTER STRIPS	65	20	65	65

3.2.4 *Export Coefficient Table*

Generally identical to the event mean concentration table, the export coefficient table lists the loading rates for each pollutant type by land use type. The rates in the export coefficient table (table 3.5) are measured in pounds per kilogram/hectare/year and are used to calculate the pollutant loads for rural land use types.

Table 3.5. Export coefficient table measured in kilogram/hectare/ per year for total phosphorus and total nitrogen (TCWP 2005).

LAND USE	TOTAL PHOSPHORUS	TOTAL NITROGEN
INDUSTRIAL/WASTE APPLICATION FIELDS	5.46	12.3
HERBACEOUS RANGELAND	1.04	5.4
MIXED FOREST LAND	0.20	0.6
MIXED URBAN OR BUILT-UP	2.23	10.0

3.3 Study Area

Three watersheds in Harris County, Texas were used in this study for the accuracy of the PLOAD tool. Within the three watersheds there are six individual hydrological units. PLOAD and hence ArcGIS-PLOAD uses the six sub units. These river basins (figure 3.2) were chosen based on the presence of urban areas and the watershed size.

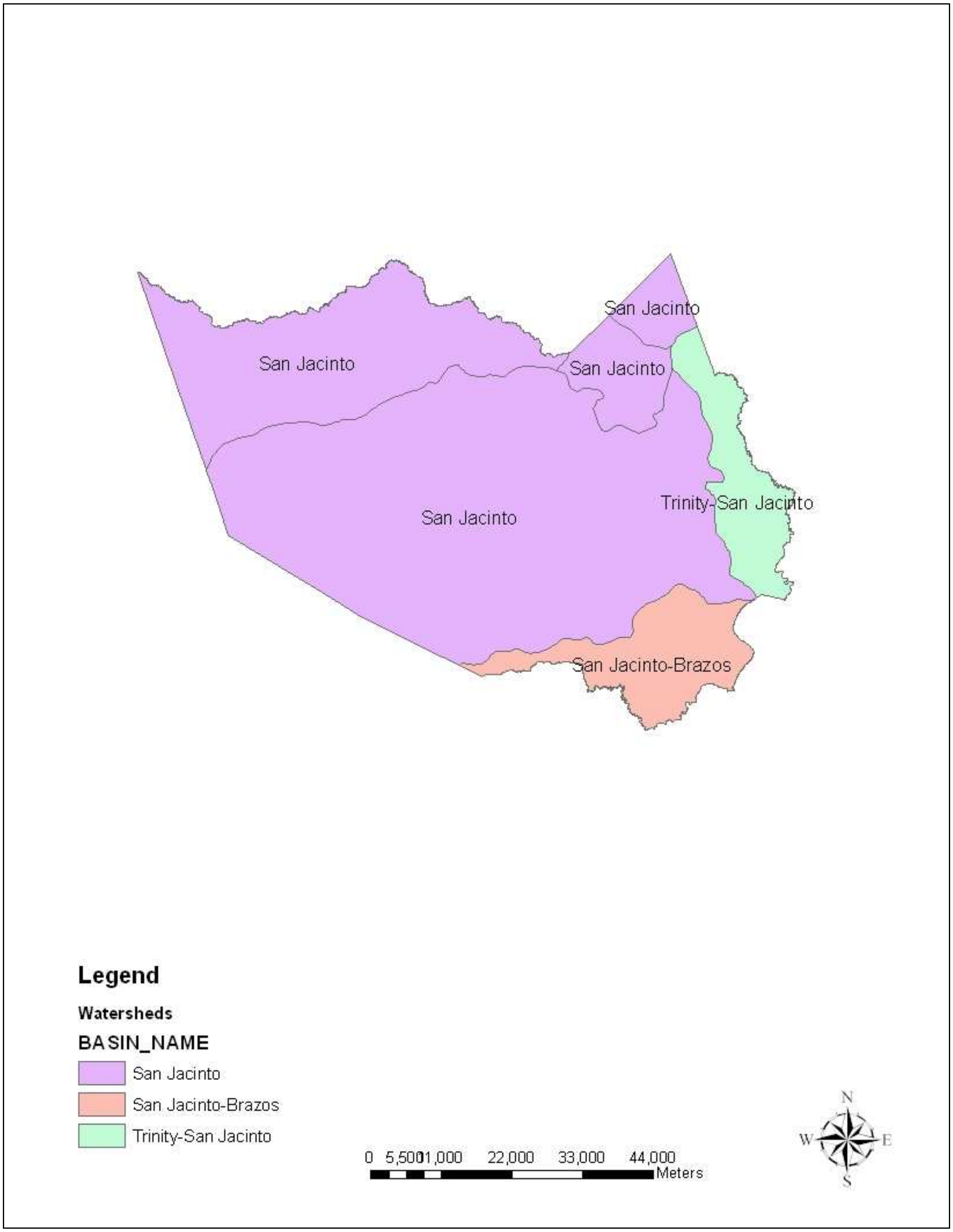

Figure 3.2. Harris County watershed boundaries (TCWP 2005).

According to U.S. Census Bureau (2006) data, Harris County has a total population of 3,400,578 people. This area encompasses roughly 48.87 miles in water and 1,728.83 miles in land and which totals approximately 1,777.69 sq miles.

Containing all of Harris and Montgomery Counties, the San Jacinto River Basin is roughly 5,600 square miles. It includes 17-state classified segments, accounting for 517 miles and two major cities, Houston and Conroe. In the Houston metropolitan areas this basin includes the most highly urbanized and industrialized portions of the city. The average rainfall for this basin ranges from 40 to 60 inches.

Also under consideration in the Harris County area is the Trinity-San Jacinto Coastal Basin. According to the (2006) census, this basin is approximately 247 square miles in drainage area. Like that of the San Jacinto River Basin, the average rainfall for this basin ranges from 40 to 60 inches. This basin includes two state-classified segments, accounting for 44 stream miles within the basin.

The San Jacinto-Brazos Coastal Basin is approximately 1,440 square miles. Including eight state-classified segments, the river basin receives on the average 35 to 70 inches in rainfall. It encompasses petroleum refining, petrochemical production, agriculture activity, and manufacturing.

3.4 Pollutant Loading Calculation Equations

PLOAD has the ability to produce maps with total pollutant loads per watershed in lb/yr. All formulas and equations required to port this application to ArcGIS Desktop came from the PLOAD user's manual (U.S. EPA 2001b). The pollutant load may be calculated for each individual watershed using two methods, the pollutant "export coefficient" or the "simple method".

3.4.1 *Export Coefficient Method*

The export coefficient method calculates loads for each specified pollutant method by watershed using the following equation:

$L_p = \sum_u (L_{pu} * A_u)$

where: L_p = Pollutant load, lbs/yr.,

L_{pu} = Pollutant loading rate for land-use type u, lbs/acre/year, and

A_u = Area of land-use type u, acres

3.4.2 *Simple Method*

The second method, the "simple method," requires two equations. The simple method estimates stormwater runoff for urban areas. This method requires the watershed area, percent imperviousness, annual precipitation and pollutant concentrations. First, the runoff coefficient for each land use type must be derived with the equation:

$R_{vu} = 0.05 + (0.009 * I_u)$

where: R_{vu} = Runoff Coefficient for land use type u, inches $_{(runoff)}$ / inches $_{(rainfall)}$

I_u = Percent Imperviousness

The pollutant loads are then calculated with the following equation:

$$L_p = \Sigma_u (P * P_J * R_{VU} * C_U * A_U * 2.72/12/4046.873) \quad (1)$$

where: L_p = Pollutant load, lb/yr

P = Precipitation, in/yr (*assumed 46 for study area*)

P_J = Ratio of storms producing runoff (*default = 0.9*)

R_{VU} = Runoff Coefficient for land use type u, inches $_{(runoff)}$ / inches $_{(rainfall)}$

C_U = EMC for land use type u, mg/1

A_U = Area of land use type u, in ac

In this project 46in/yr was used for all 5 basins. The fraction of storms producing runoff (P_J) was 0.9. The loading rates (C_U) are obtained from the EMC tables, and the land-use areas are obtained from the individual polygons in the intersection layer. Equation (1) is a simple blow-up of C_U (mg/l) accumulation in runoff precipitation by P, P_J, and R_{VU} from (in/yr) to lb/yr.

3.5 Executing ArcGIS-PLOAD Application

The main objective of this study was to port PLOAD to ArcGIS Desktop efficiently and with as few “appearance” changes as possible in order to minimize “disruption” for current users of PLOAD considering moving their applications to ArcGIS-PLOAD. With the use of tabular data, input GIS data, and the given formulas to calculate the “simple method” custom scripts were written using VBA to successfully run the new tool. The VBA scripts will be made available form the Texas A&M University Spatial Sciences Laboratory website (ww-ssl.tamul.edu) once the export coefficient method is fully developed and once the use of BMPs have been imported. ArcGIS-PLOAD is a geodatabase application. This allowed for the calculations to be made very simply using a few SQL (figure 3.3) queries. The main query is:

```
TRANSFORM Sum (SimpleMethod.Lp_tn) AS SumOfLp
SELECT SimpleMethod.HUC, SimpleMethod.BASIN_NAME, Sum(SimpleMethod.Lp_tn) AS
TotalLp
FROM
   SELECT *,
     0.05+0.009*LUParams.Imperv AS rvu,
     46*0.9*rvu*BOD*2.72/12*Shape_Area/4046.873 AS Lp_BOD,
     46*0.9*rvu*TSS*2.72/12*Shape_Area/4046.873 AS Lp_TSS,
     46*0.9*rvu*TN*2.72/12*Shape_Area/4046.873 AS Lp_TN,
     46*0.9*rvu*TP*2.72/12*Shape_Area/4046.873 AS Lp_TP
   FROM
     LuParams
     INNER JOIN intersect1
     ON LUParams.LUCode =intersect1.GRIDCODE
 . AS SimpleMethod
GROUP BY SimpleMethod.HUC, SimpleMethod.BASIN_NAME
PIVOT SimpleMethod.GRIDCODE
```

Figure 3.3. SQL queries used to make calculations.

The remainder of this chapter addresses user interface and the execution of ArcGIS-PLOAD.

3.5.1 *The User Interface*

This section will describe how the user is to begin and run the automated tool in ArcMap. It is assumed that user has already opened ArcMap to begin the execution of the automated tool. There are three primary steps that user is required to complete the calculations. This tool was developed to allow for custom application for each user.

In the first step the user is required to identify that the necessary input data is available. After doing so, the custom application prompts the user to initialize the program by selecting the pollutant tool button (figure 3.4) on the ArcMap toolbar. By selecting this button the user begins the session.

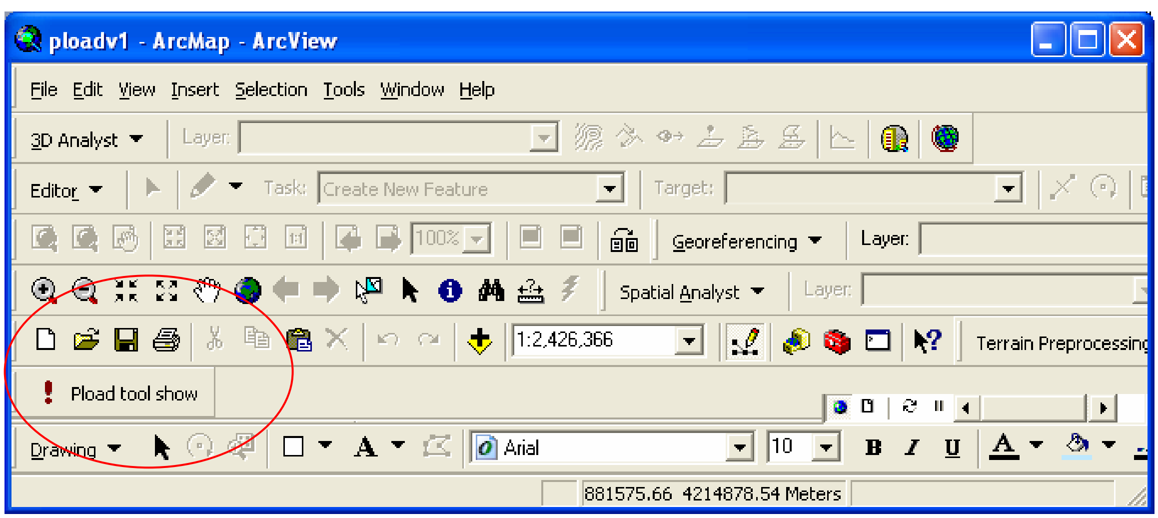

Figure 3.4. PLOAD tool show button to initialize the start of the ArcGIS-PLOAD.

Once the tool is initialized the Session Manager window appears which allows the user to start a new session (figure 3.5). The user selects a new session to begin the automated tool process and closes the session manager. By selecting "*new session*", the automated tool scenario can be used to start a new session. The "*new session*" buttons also clears ay layers that may appear on the map. This ensures the appropriate layers are used in the calculations.

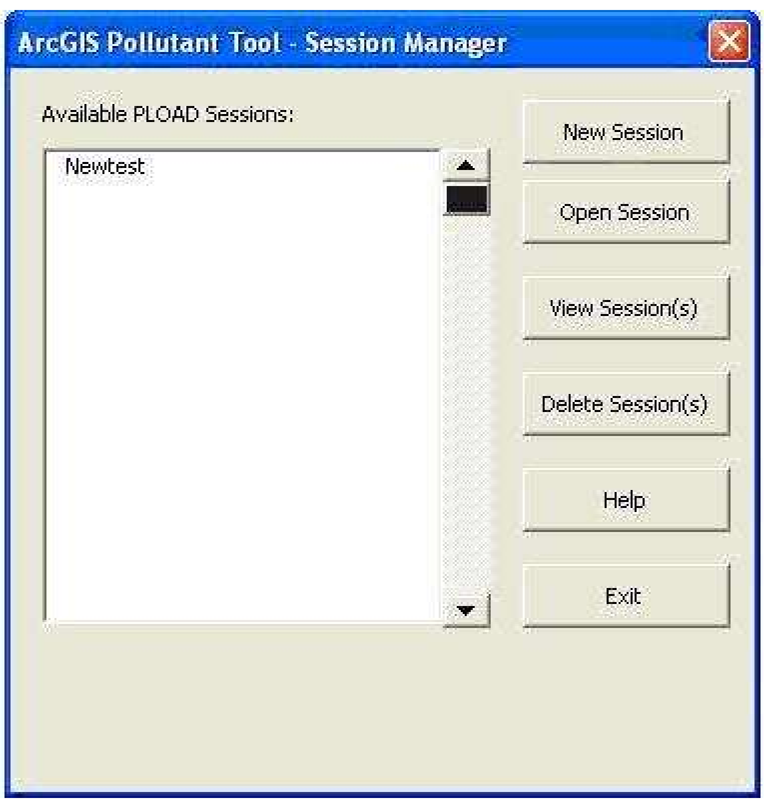

Figure 3.5 ArcGIS-PLOAD tool session manger startup screen.

Once the new session tool is selected the pollutant parameters form appears (figure 3.6). After receiving the necessary information from an Excel spreadsheet which contains data information, the user is allowed to complete several steps.

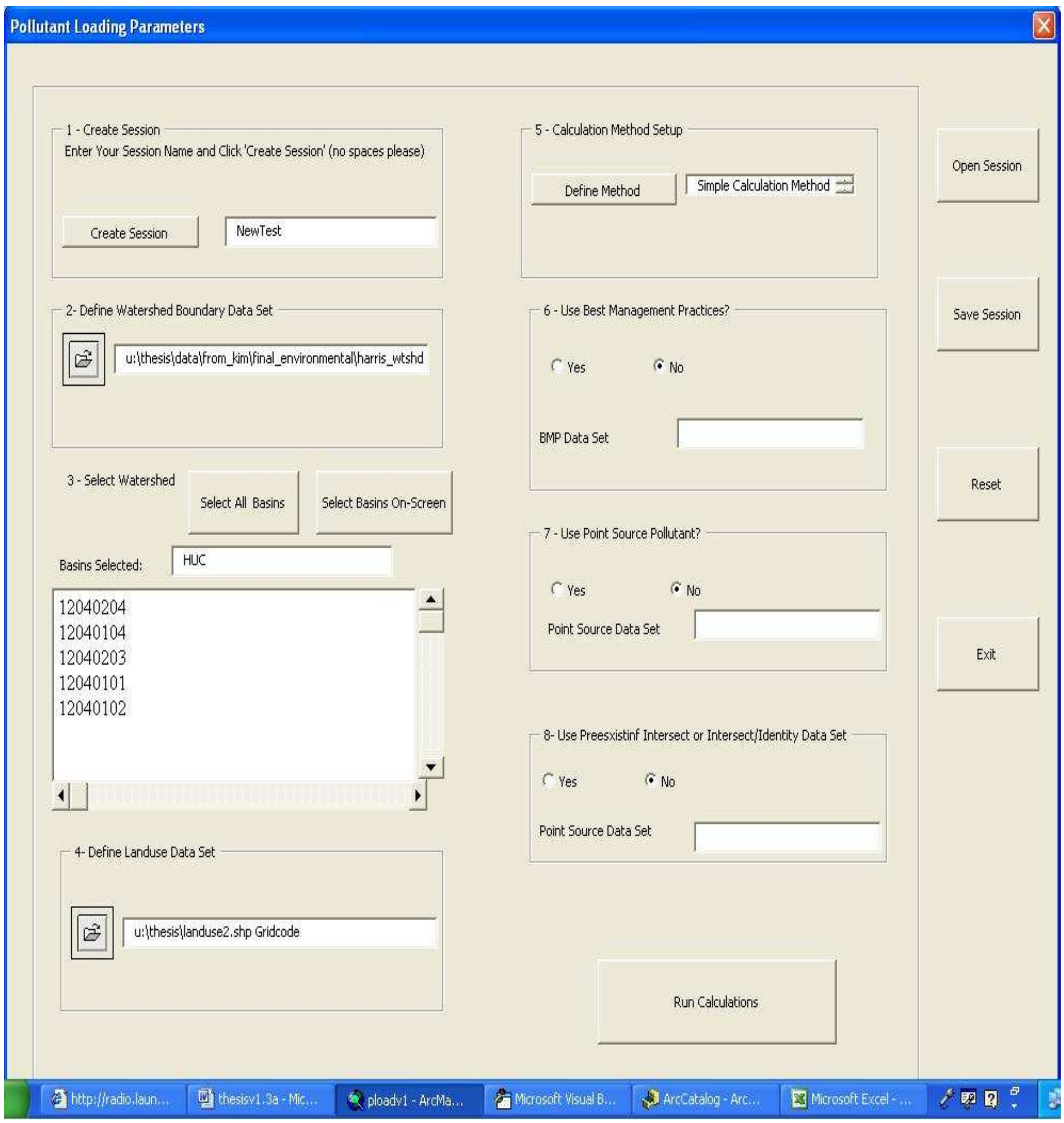

Figure 3.6. Pollutant parameters dialog box for user input to complete the calculation for total pollutant loads in the ArcGIS-PLOAD.

The create session, allows the user to give the particular session a desired name. The session “NewTest” was created. The second step requires defining a watershed boundary, which comes from the watershed basins data. The user has to specify which watershed basins should be calculated. For the purposes of this study, six different watersheds were chosen to evaluate within Harris County. The user is prompted to define the land use data set. As mentioned before the HGAC land use data was used. The specified calculation method used was “simple method.” This method requires for an annual precipitation value and default value for the ratio of storms producing runoff. Best management practices, the use of point source pollutants, or preexisting intersect data was not examined.

The “simple method” is the only method that was used for this study. After selecting all of the necessary parameters, the user is to run the calculations. These necessary parameters include specifying which pollutants that will be examined such as the percent impervious table and the event mean concentration tables.

With the formulas embedded within the VBA scripts, the calculations are performed using the Microsoft Access query noted above and returned to Arc Map to complete the calculated pollutant in pounds per year for each of the given watershed basins.

3.6 Executing PLOAD

With the same parameters chosen as that of the automated tool, PLOAD was also executed. The PLOAD Session Manager window (figure 3.7) appears and with the selection of “new session”, the Session Manager window closes.

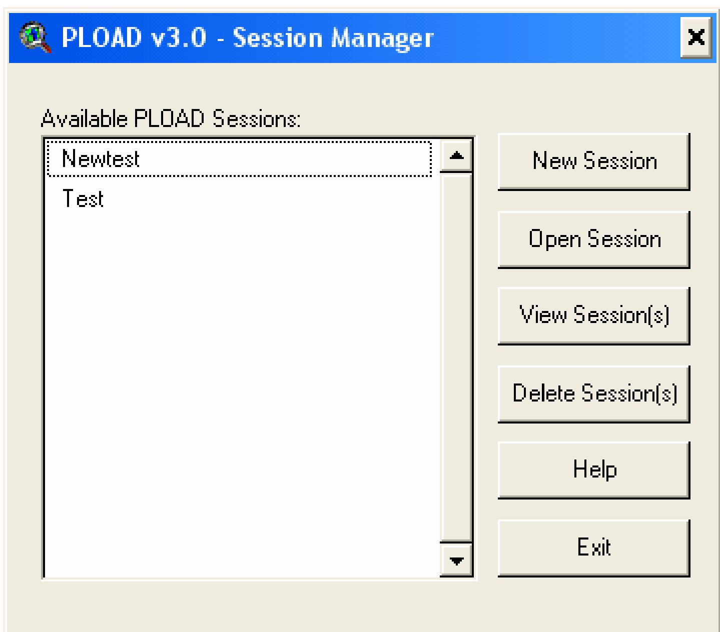

Figure 3.7. PLOAD v3.0 session manger window.

The Pollutant Loading Parameters dialog window (figure 3.8) next appears. Same as the automated tool, this session was named “new test.” Next the Harris County watershed boundary was chosen and the appropriate field with the unique identifier for the watershed was chosen. This was used for the output tables and graphical layouts.

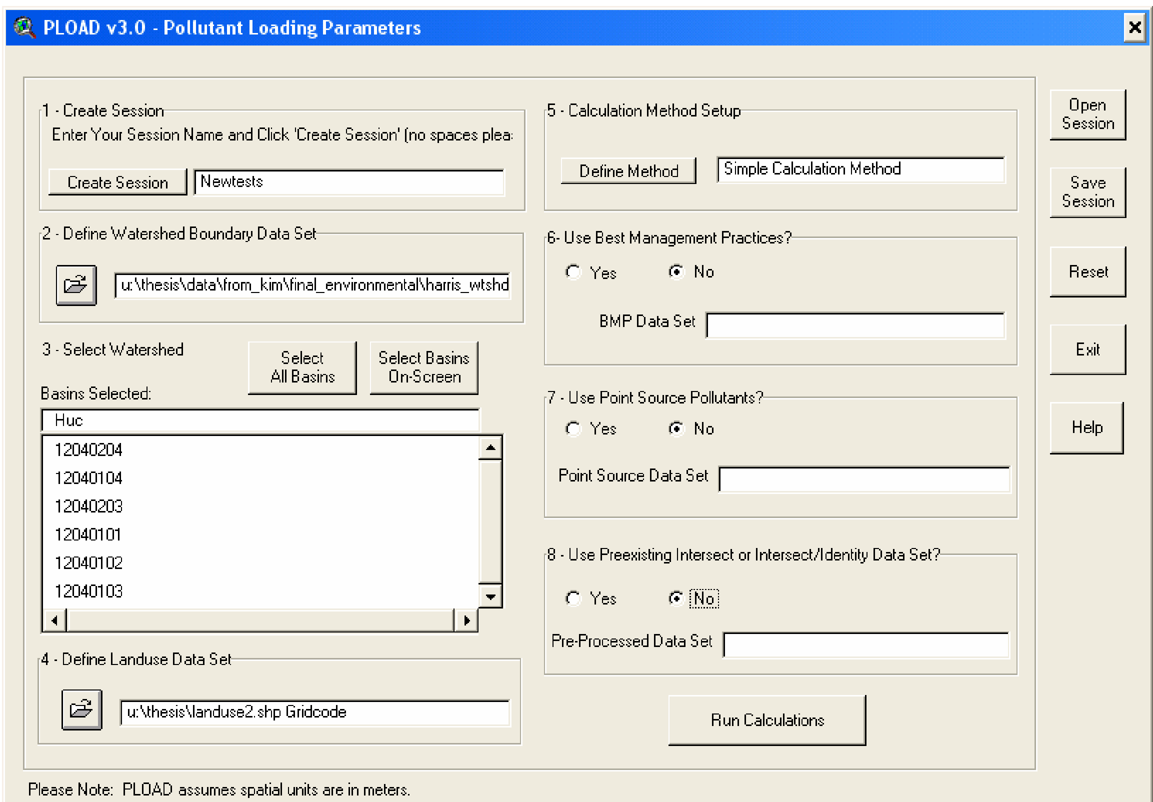

Figure 3.8. PLOAD pollutant loading parameters dialog window.

The land use dataset was then defined and the attribute that contained the land use field was chosen. The “simple method” calculation was chosen and the tables were loaded. Best management practices, point source pollutants, or existing intersecting data will not be used. The total pollutant in pounds per year were calculated for each of the given watershed boundaries.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Evaluation of ArcGIS-PLOAD

To determine the accuracy and the possible error in completing the ArcGIS-PLOAD a simulation of the PLOAD model was conducted. In this simulation time comparisons between the original PLOAD and the new ArcGIS-PLOAD revealed significant improvements. The computational demands of the original PLOAD were such that several attempts were necessary even to get PLOAD to run on the Harris-Galveston area data. After several hours the computers would simply lock-up requiring a re-boot. After several attempts PLOAD analyzed the Houston-Galveston data in their entirety but required a whopping 23+ hours to complete the calculation. A “second” attempt with identical inputs required a little over eight hours. The differences between these “extremes” were not investigated further as being tangential to this study. What is important is that the original PLOAD required several attempts and then several hours to analyze the Houston-Galveston data.

For the eight-hour run, the intersecting of land use data and watershed data, which is a necessity in completing the calculations, had duration of approximately six hours. The ArcGIS-PLOAD duration was 20 minutes.

With calculations done to the intersecting layer, it was found that the original PLOAD disregarded an, albeit relatively small, portion of the intersection polygons (figure 4.1). The ArcGIS-PLOAD does not.

Figure 4.1. Missing data in the intersect shapefile obtained from PLOAD. The white areas are omitted from calculations in the PLOAD (TCWP 2005).

4.2 Comparison of Total Pollutants in the Automated Tool and PLOAD

For each of the pollutants modeled in the application both graphical and tabular outputs were created per watershed boundary, summarizing total pollutant loads in lbs/year for the following pollutants: Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS). The higher the number indicated the higher impacts on watershed basis, and thus on water quality. The values derived from Arc-GIS PLOAD can evaluate nonpoint source pollutions. These values can pinpoint the problem areas for specific watersheds and can thus assist decision makers as they attempt to decrease the amount of pollution in the future.

4.2.1 *Biochemical Oxygen Demand (BOD)*

In PLOAD the total pollutant loads for Biochemical Oxygen Demand (BOD) in lbs per year is 5,509,956 (table 4.1). The ArcGIS-PLOAD total pollutant loads for Biochemical Oxygen Demand (BOD) in lbs per year is 5,453,892. The percent difference relates to the missing data in the intersection layer. When run against just the missing polygons, ArcGIS-PLOAD produced, exactly, the difference between ArcGIS-PLOAD values on all polygons. In addition to output tables, ArcGIS-PLOAD and PLOAD produces output maps (figure 4.2).

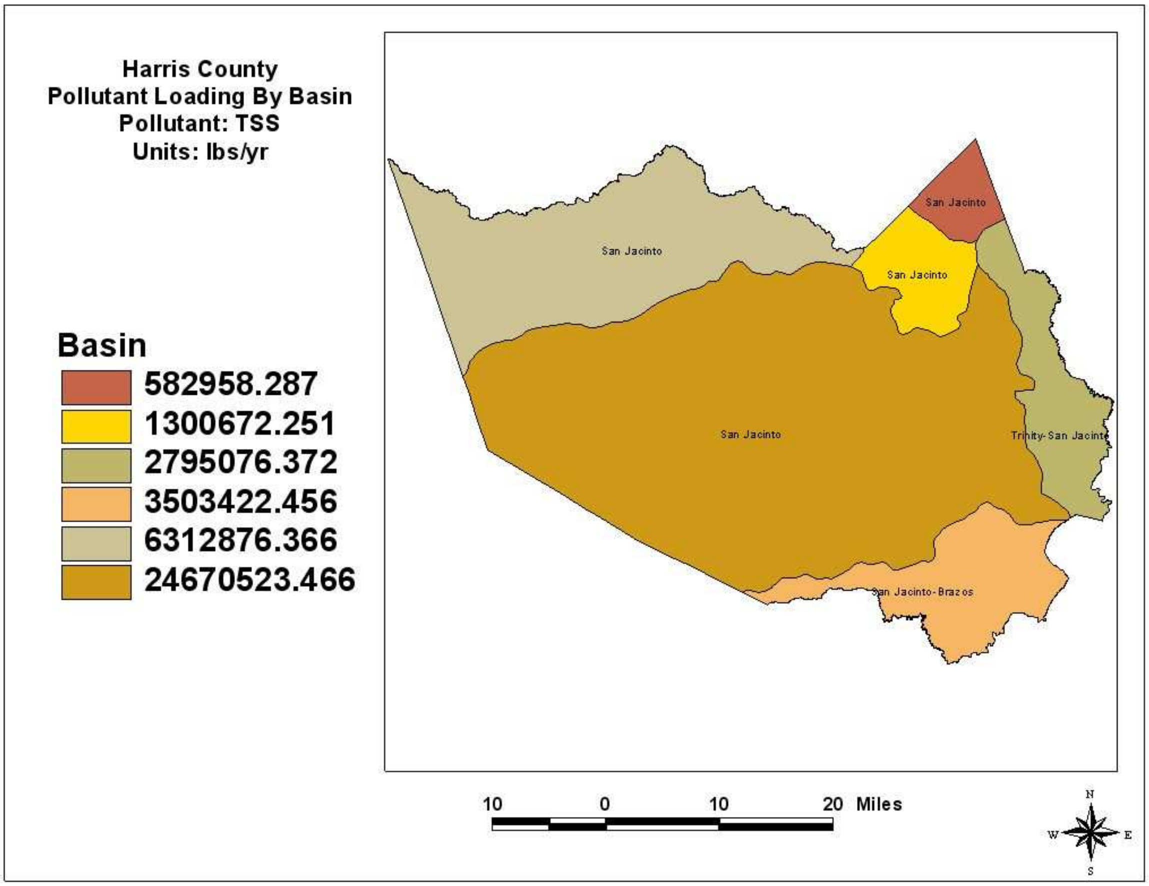

Figure 4.2. Total pollutant loads for Total Suspended Solids (TSS) in lbs/yr for Harris County, TX using the traditional PLOAD. The TSS loading amounts are represented in unique color for each watershed boundary.

Table 4.1. Total Biochemical Oxygen Demand in lbs/yr in PLOAD and ArcGIS-PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

BASIN NAME	**HUC**	**BOD- Pollutant in lbs/yr.**	**BOD- Pollutant in lbs/yr.**	**Percent Difference**
San Jacinto	12040101	301,042	301,879	.28%
San Jacinto	12040102	706,993	821,172	16.15%
San Jacinto	12040103	94,422	99,400	5.27%
San Jacinto	12040104	3,568,752	3,609,089	1.13%
Trinity-San Jacinto	12040203	324,516	399,400	.69%
San Jacinto-Brazos	12040204	514,227	522,950	1.70%

4.2.2 *Total Nitrogen (TN)*

In PLOAD the total pollutant loads for Total Nitrogen (TN) in lbs per year is 1,777,538 (table 4.2). The ArcGIS-PLOAD tool total pollutant loads for Total Nitrogen (TN) in lbs per year is 1,819,245 . The percent difference relates to the missing data in the intersection layer.

Table 4.2. Total Nitrogen (TN) in lbs/yr in PLOAD and ArcGIS-PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

BASIN NAME	HUC	PLOAD: TN- Pollutant in lbs/yr.	ARCGIS APPLICATION TN- Pollutant in lbs/yr.	PERCENT DIFFERENCE
San Jacinto	12040101	183,904	184,094	.10%
San Jacinto	12040102	181,837	209,151	15.02%
San Jacinto	12040103	34,179	34,868	2.01%
San Jacinto	12040104	1,079,861	1,088,454	9.08%
Trinity-San Jacinto	12040203	133,473	136,365	2.17%
San Jacinto-Brazos	12040204	164,281	166,310	1.23%

4.2.3 *Total Phosphorus (TP)*

In PLOAD the total pollutant loads for Total Phosphorus (TP) in lbs per year is 196,874 (table 4.3). The automated tool total pollutant loads for Total Phosphorus (TP) in lbs per year is 201,386. The percent difference relates to the missing data in the intersection layer.

Table 4.3.Total Phosphorus (TP) in lbs/yr in PLOAD and ArcGIS-PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

BASIN NAME	HUC	TP- Pollutant in lbs/yr.	TP- Pollutant in lbs/yr.	Percent Difference
San Jacinto	12040101	6,484	6,528	.68%
San Jacinto	12040102	19,291	21,822	13.12%
San Jacinto	12040103	1,700	1,750	2.92%
San Jacinto	12040104	140,876	142,228	.96%
Trinity-San Jacinto	12040203	9,578	9,808	2.40%
San Jacinto-Brazos	12040204	18,943	19,248	1.61%

4.2.4 *Total Suspended Solids (TSS)*

In PLOAD the total pollutant loads for Total Suspended Solids (TSS) in lbs per year is 39,165,529 (table 4.4). The highest concentration of the TSS occurs in the San Jacinto River Basin (HUC 12040104). The low concentration of TSS occurs in the San Jacinto River Basic (HUC 12040103). The automated tool total pollutant loads for Total Suspended Solids (TSS) in lbs per year is 40,995,071.

4.2.5 *Total Pollutants in lbs/acre*

To better compare pollutants between basins the annual pollutant load, pounds per acre (tables 4.5 and 4.6) was calculated for each river basins. Due to different sizes (table 4.7) of the river basins, the per acre values provide an better picture of the relative amounts of the pollutants for each watershed. We see for example that basin 12040104 has the highest TSS of all of the river basins. This is likely a reflection of the fact that 12040104 is the most populated and impervious, with more TSS being washed out in the runoff.

Table 4.4. Total Suspended Solids (TSS) in lbs/yr in PLOAD and ArcGIS-PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

BASIN NAME	HUC	TSS- Pollutant in lbs/yr.	TSS- Pollutant in lbs/yr.	Percent Difference
San Jacinto-Brazos	12040101	1,300,672	1,306,246	.43%
San Jacinto	12040102	6,312,876	7,569,209	19.90%
Trinity-San Jacinto	12040103	582,958	615,313	5.55%
San Jacinto	12040104	24,670,523	24,993,727	1.31%
Trinity-San Jacinto	12040203	2,795,076	2,929,144	4.80%
San Jacinto-Brazos	12040204	3,503,422	3,581,429	2.22%

Table 4.5. Total pollutants in lbs/acre in PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

Basin Name	**HUC**	**BOD-Pollutant in lb/ac/yr**	**TN-Pollutant in lb/ac/yr**	**TP-Pollutant in lb/ac/yr**	**TSS-Pollutant in lb/ac/yr**
San Jacinto-Brazos	12040101	6.211	3.794	0.134	26.837
San Jacinto	12040102	3.613	0.929	0.099	32.265
Trinity-San Jacinto	12040103	3.853	1.394	0.069	23.790
San Jacinto	12040104	5.559	1.682	0.219	38.430
Trinity-San Jacinto	12040203	4.380	1.801	0.129	37.725
San Jacinto-Brazos	12040204	5.359	1.712	0.197	36.513

Table 4.6. Total pollutants in lbs/acre for ArcGIS-PLOAD. The HUC is the hydrologic unit code to identify each hydrologic unit.

Basin Name	**HUC**	**Area (acres)**	**%Impervious Cover**
San Jacinto-Brazos	12040101	48,576	19
San Jacinto	12040102	234,225	16
Trinity-San Jacinto	12040103	26,297	21
San Jacinto	12040104	651,862	20
Trinity-San Jacinto	12040203	78,331	18
San Jacinto-Brazos	12040204	98,277	20

4.2.6 *Percent Impervious Cover*

A key indicator of potential watershed and stream health, percent impervious cover can be used to correlate the link between land use and water pollution potential. Many studies indicated that stream quality, habit and even wetlands become impaired when the percent impervious cover in a watershed exceeds 10 to 20 percent (Greig *et al.* 1998). Showing (table 4.7) the percent impervious for the Harris County watersheds ranging from 16% - 20%. The watershed basins surpass the recommended 10% impervious cover which potentially indicates stressed conditions and relatively high pollutant values.

Table 4.7. Estimated percent impervious cover of river basins. The HUC is the hydrologic unit code to identify each hydrologic unit.

Basin Name	**HUC**	**BOD-Pollutant in lb/ac/yr**	**TN-Pollutant in lb/ac/yr**	**TP-Pollutant in lb/ac/yr**	**TSS-Pollutant in lb/ac/yr**
San Jacinto-Brazos	12040101	6.215	3.790	0.134	26.891
San Jacinto	12040102	3.508	0.893	0.093	32.332
Trinity-San Jacinto	12040103	3.784	1.328	0.067	23.426
San Jacinto	12040104	5.537	1.670	0.218	38.343
Trinity-San Jacinto	12040203	4.299	1.745	0.125	37.477
San Jacinto-Brazos	12040204	5.330	1.695	0.196	36.505

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The release of non-point source pollutions into drainage systems of urban areas has become a major problem in America today (U.S. EPA 2006b). With the objective to utilize ArcGIS to assist in solving the growing concern to improve land-use decision making with regards to water quality, PLOAD was ported from ArcView 3.3 to an ArcGIS geodatabase application using ArcObjects. Time comparisons between the original PLOAD and the new ArcGIS-PLOAD revealed significant time improvements from 23+ hours to 20 minutes. Missing polygons from the original PLOAD intersection were also discovered.

The test analysis was based on the assumptions the annual precipitation 46 inches and ratio of storms producing runoff was left as the default value of 0.9. These values depends on pollutant (per acre) that the highest annual loads are in the largest San Jacinto river basin. This is not surprising given the size of each watershed as to this river basin. ArcGIS-PLOAD demonstrated the capabilities of calculating the total pollutant loads in pounds per year for Harris County watersheds. With successful implementation of the automated tool, it is intended to identify possible problems for Harris County watersheds. The total pollutant amounts in pounds per acre give a better estimate as regards to the size of the actual basin itself. By giving an estimate of the non point source pollutants for this area on an annual average basis, it is hoped that this will assist in watershed management.

There were significant improvements in the reduction in time to run the test data in the ArcGIS-PLOAD. The PLOAD had problems with the original intersection of layers was identified.

Using NEMO as a tool and resource, ArcGIS will have the capabilities to be used as an educational tool for municipal officials and facilitate change in local land-use plans, programs, and policies. According to NEMO, "its project's track record shows that effective, carefully planned educational programs conducted by professionals can catalyze and facilitate change."

5.2 Recommendations

As technology continues to advance and the utility of this tool becomes more apparent, a goal of this project to was to create a parsimonious tool that would be easily refined and expanded the limitations in the automated tool and check for correctness.

The automated tool neglects to encompass all of PLOAD calculations. Future extensions of this tool will include the implementation of the other method, “export coefficient”. Secondly, the extensions will also include the incorporation of Best Management Practices (BMPs). This will assist educating municipal officials about how to reduce pollutant loads by examining results of simulations of the total pollutant loads based on the remedial effects of various types of BMPs.

With a concerted effort to provide officials with tools to help meet national water quality standards, there is an ever increasing need for educational tools. These tools enable officials to do a better job planning and developing there communities. To surmount the problems facing local decision makers, ArcGIS-PLOAD will be used to educate municipal officials to facilitate change in local land use plans, programs and policies. Technologies of the ArcGIS-PLOAD will help communities to remedial their pollutants to meet national standards. Images and tables produced from the ArcGIS-PLOAD enables users to present information on land use in a succinct and intuitive way. Using tables and colorful documents of images of key environmental data go a long way towards explaining the concepts of the total pollutant in a particular watershed. This tool can be used in a multi-faceted way to present quality information to planners, municipal officials on various watershed projects.

With addition resources, Arc-GIS PLOAD will develop into an extended web-service application. According to NEMO (1999), a goal to further disseminate information is using the World Wide Web. This application will allow users to access and manipulate maps without having to own the GIS software.

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